Cuspal deflection and depth of cure in resin-based composite restorations filled by using bulk, incremental and transtooth-illumination techniques

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Polymization shrinkage of restorative resin-based composites has been associated with microleakage, debonding, secondary caries and postoperative sensitivity. Among the techniques suggested to reduce polymization shrinkage stress is the incremental placement of composite material, in which the clinician typically places the material in small increments of 2 millimeters or less and then photo-activates it from an occlusal direction. Although the incremental technique may be necessary for adequate light penetration, its disadvantages include the possibility of trapping voids or contamination between layers and the increased time required to place the restoration. The benefit of using an incremental technique for reducing shrinkage stresses has been questioned on the basis of numerical and experimental analyses. Idriss and colleagues found no significant difference between bulk and incremental filling techniques when they examined marginal gap size in Class II composite restorations in vitro.

Besides filling techniques, the direction of shrinkage also often is regarded as an important factor in controlling shrinkage patterns in restorations. It once was believed that resin-based composite shrinks toward the source of light and thus could be manipulated to obtain a beneficial shrinkage orientation during photo-curing. This has been challenged by several authors who have shown that the direction of shrinkage is dependent upon the material used and the filling technique selected. A number of studies have been performed using microcomputed tomography to examine the direction of shrinkage in Class II composites. These studies have shown that the direction of shrinkage is affected by the filling technique selected. The purpose of this study was to examine the direction of shrinkage in Class II composites filled with the incremental technique.

Background. Restoration techniques affect shrinkage stress and depth of cure. The authors tested cuspal deflection and depth of cure resulting from the use of different techniques (bulk, incremental, bulk/transtooth illumination) and two resin-based composites (deep curing and conventional).

Methods. The authors restored extracted teeth with deep-curing X-tra fil (VOCO, Cuxhaven, Germany) (by using bulk and incremental techniques) and Filtek Supreme Plus (3M ESPE, St. Paul, Minn.) (by using bulk, incremental and bulk/transtooth-illumination techniques). The sample size for each technique was five. They determined cuspal deflections as changes in buccal and lingual surfaces before and after restoration. To determine the extent of cure, they measured hardness 0.5 to 3.5 millimeters deep on the sectioned restorations.

Results. The authors found no difference in cuspal deflection between filling techniques within the same materials (P > .05). They found no difference in hardness for X-tra fil at any depth with either the bulk or the incremental technique (P > .05). Filtek Supreme Plus had higher hardness values at depths of less than 1.5 mm with the bulk/transtooth-illumination technique, whereas the bulk technique resulted in lower hardness values at depths of 2.0 mm and below (P < .05).

Conclusions. Cuspal deflection was not affected by filling techniques. X-tra fil cured up to a depth of at least 3.5 mm; Filtek Supreme Plus had lower curing values below a depth of 2 mm. The transtooth-illumination technique improved curing depth for restorations placed in bulk.

Clinical Implications. When using resin-based composite restorative materials, clinicians should be more concerned about the effect of filling techniques on curing depth than about how these techniques affect shrinkage stresses.

Key Words. Composite; cuspal flexure; cure; bulk; incremental; transtooth illumination; hardness.

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activation. Versluis and colleagues\textsuperscript{11} pointed out that composite does not shrink toward the light and that, rather, the direction of shrinkage is determined predominantly by the presence or absence of a bond. This observation has been helpful for rationalizing curing protocols. Belvedere\textsuperscript{12} proposed that a transenamel illumination technique involving light curing of a bulk-placed composite from buccal and lingual directions, and thus through the tooth enamel, can achieve the advantages of bulk placement while avoiding the disadvantages of incremental techniques. Light transmitted through the tooth structure initially polymerizes the most critical areas along the interfaces, establishing adequate bonding before polymerization shrinkage of the inner bulk interferes.\textsuperscript{12}

Although low residual stress and good adaptation are important, thorough polymerization is an equally important consideration for any filling technique. The main concern regarding a bulk technique is whether the composite cures fully enough in the deeper portions to create a material that has acceptable physical and biocompatible properties. Using microhardness at various restoration depths as an indicator, Lazarchik and colleagues\textsuperscript{13} showed that the extent of polymerization was not different between bulk-filled and incrementally filled restorations of a light-shade composite, whereas the bulk technique resulted in significantly lower microhardness values in a material of a darker shade. However, Amaral and colleagues\textsuperscript{14} found no difference in microhardness at any depth between the bulk-placed and incrementally placed restorations, provided that the restorations were exposed to light from occlusal, buccal and lingual directions. Thus, the transtooth-illumination technique also may overcome the concern regarding depth of cure that is associated with bulk placement.

We conducted an in vitro study to investigate whether a bulk-placement technique affects shrinkage stress, and whether the clinician can prevent a compromised depth of cure by using a more deeply curing composite or by using the transtooth-illumination technique. Because shrinkage stress itself cannot be measured directly, we assessed its effect by measuring cuspal deflection of restored teeth. We assessed the extent of cure by measuring microhardness at various depths. To compare the effect of shrinkage stress between bulk-restored and incrementally restored teeth, we used a composite designed to cure up to a depth of 4 mm. This provided sufficient depth of cure to allow comparison of shrinkage stress effects from the two techniques. We used a conventional composite to compare the effects of transtooth illumination of a restoration placed in bulk with conventional bulk and incremental techniques.

**METHODS**

We chose for the study a hybrid composite that its manufacturer claims has a curing depth of 4 mm (X-tra fil, Universal shade, VOCO, Cuxhaven, Germany) and a nanocomposite (Filtek Supreme Plus, A2D shade, 3M ESPE, St. Paul, Minn.).

**Sample preparation and digitization.** The study protocol, which the institutional review board of the University of Minnesota, Minneapolis, designated as exempt, involved the use of 25 extracted human teeth. We secured the teeth in stainless steel rings (Figure 1A) and kept them immersed in water throughout the protocol to prevent desiccation. Each ring contained four embedded spheres surrounding the tooth sample, which functioned as stable reference areas. We sandblasted the spheres and etched the tooth enamel with 37 percent phosphoric acid solution to obtain dull surfaces suitable for optical scanning.

We prepared a large, slot-shaped mesioocclusal-sidistal cavity (4 mm deep, 4 mm buccolingual width) with a no. 245 carbide bur in a high-speed handpiece under copious amounts of water. The mean (standard deviation [SD]) wall thickness, measured at the middle of the restoration wall, was 2.39 (0.34) mm. After preparation, we digitized images of the teeth along with their reference spheres with an optical scanning system (LavaScan ST, 3M ESPE); the digital models had an estimated resolution of 60 micrometers and 5-μm accuracy (Figure 1B). We calibrated the scanner each day before conducting the experiments.

**ABBREVIATION KEY.** TT: Transtooth.
Experimental groups. We carried out two independent sets of experiments, one in which we restored teeth with X-tra fil and the other in which we restored teeth with Filtek Supreme Plus. We determined the sample size needed to enable us to detect a mean difference of one SD with a 95 percent confidence, on the basis of previous studies in which investigators used the same methodology.\(^{15,16}\)

X-tra fil. We divided 10 teeth (six premolars and four molars) to be restored with X-tra fil into two groups (each \(n = 5\)) of matched pairs for shape and size; hence, each group contained three premolars and two molars. We filled each pair randomly with an incremental or a bulk technique. There was no significant difference in wall thickness between the two groups (\(P = .05\)).

Filtek Supreme Plus. We divided 15 matched premolars to be restored with Filtek Supreme Plus into three groups (each \(n = 5\)). We randomly filled the sets of three matched teeth with a bulk, an incremental or a transtooth-illumination bulk technique. There was no significant difference in wall thickness between the three groups (\(P = .05\)).

Filling and curing techniques. For the bulk technique, we placed the composite in one increment (4 mm) and light cured it for 20 seconds simultaneously with two curing lights through the buccal and lingual surfaces, followed by 20 seconds from the occlusal direction. We used two high-intensity curing units (CureMax V LED Curing Light, Maximum Dental, Secaucus, N.J., and Allegro High-Intensity LED, Den-Mat, Santa Maria, Calif.). The light intensities, measured with the radiometer built into the Allegro charging unit, were 1,238 milliwatts per square centimeter and 1,294 mW/cm\(^2\), respectively.

Bonding protocol. We used the same bonding protocol in each technique. We etched the cavity surfaces with 34 percent phosphoric acid (Caulk 34% Tooth Conditioner gel, Dentsply Caulk, Milford, Del.) for 15 seconds, rinsed them with water for 10 seconds, blotted them dry, applied Prime & Bond NT (Dentsply Caulk) for 20 seconds, lightly air dried them for five seconds and light cured them for 20 seconds. After we finished the restorations, we wiped the composite surfaces with an alcohol pad to remove the oxygen-inhibition layer. We did not polish the restorations. Immediately after restoration, we digitized the teeth in the LavaScan system.

Cusp flexure analysis. We accurately aligned the digitized tooth surfaces before and after restoration by using Cumulus software (copyright Regents of the University of Minnesota), fitting the stainless steel reference sphere surfaces in three dimensions.\(^{17}\) By using a custom-developed software (CuspFlex), we calculated contour changes perpendicular to the original tooth surfaces. We selected the buccal and lingual surfaces above the gingival level of the restoration up to the cusp ridges as the areas subjected to cuspal deflection. We defined cuspal deflection as the difference between the restored tooth and the prepared tooth, determining the differences perpendicular to the buccal or lingual surfaces. A linear color scale was used to visualize changes in the tooth surfaces (Figure 2). We determined the average cuspal deflection of each surface by calculating the notional volume change (difference integrated over the buccal and lingual surfaces) divided by the surface area. The coronal deformation was the sum of buccal and lingual cuspal deflections.\(^{15,16}\)

Microhardness determination. After scanning, we cross-sectioned the restored teeth buccolingually at the highest point of the cusp, perpendicular to the long axis of the tooth. We embedded the two halves in Orthodontic Resin (LD Caulk, Milford, Del.), and we polished the cross-sectioned surfaces serially by using a grinder-polisher.
We measured microhardness of the composite restorations by using a hardness tester (MicroMet 5104, Buehler) with a Vickers indenter at 200g load. We made a series of indentations along the long axis of the tooth in the center of the restoration at 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 mm from the occlusal surface. We evaluated both halves of the restorations. The hardness value at each depth was the average of both sides.

**Statistical analysis.** To analyze the differences between the filling techniques for coronal deformation and for microhardness at each depth, we used the t test for X-tra fil and one-way analysis of variance (ANOVA) followed by the Student-Newman-Keuls (SNK) post hoc test for Filtek Supreme Plus. In addition, we analyzed the hardness differences among various depths for the same filling technique and the same composite by using one-way ANOVA followed by the SNK test. We performed all statistical analyses at a significance level of .05. We made no comparison between X-tra fil and Filtek Supreme Plus.

**RESULTS**

**Cuspal deflection.** The cusps of all teeth moved inward after restoration (Figure 2). In general, Filtek Supreme Plus caused more cuspal deflection than did X-tra fil. Table 1 lists the coronal deformation values, defined as the sum of the buccal and lingual cuspal deflection values. We found no significant difference among the filling techniques within the same composite material (*P* > .05).

**Microhardness.** Table 2 and Figure 3 (page 1181) show the measured microhardness values of the restorations at various depths. In general, X-tra fil restorations had hardness values higher than those of Filtek Supreme Plus. Figure 3 contains statistical results of the hardness differences among filling techniques (within the same composite material) at each depth. For X-tra fil, we found no significant difference between the bulk and incremental techniques at any depth (*P* > .05). For Filtek Supreme Plus, the hardness values of composite restored with the bulk/transtooth-illumination technique were significantly higher than those of composite restored with the bulk or incremental techniques at depths of 0.5, 1.0 and 1.5 mm, and the hardness values of composite restored with the bulk technique were significantly lower than those of composite restored with the bulk/transtooth-illumination or incremental techniques at depths of 2.0, 2.5, 3.0 and 3.5 mm (*P* < .05). The bulk/transtooth-illumination technique tended to produce hardness values higher than those of the other two techniques.

Table 2 contains statistical results of the hardness differences among various depths for each filling technique. For X-tra fil, there was no significant difference in hardness between various depths for either filling technique (bulk or incremental, *P* > .05). For Filtek Supreme Plus, we found some differences between hardness values at various depths with all filling techniques. In Filtek Supreme Plus restorations placed with the bulk technique, hardness values at 2.5, 3.0 and 3.5 mm were significantly lower than those at 0.5 and 1.0 mm (*P* < .05). The hardness profile in the Filtek Supreme Plus group restored incrementally showed values decreasing between 0.5 and 1.5 mm, increasing at 2.0 mm and then decreasing again. Hardness values at 3.0 and 3.5 mm were significantly lower than those at 0.5 mm. In Filtek Supreme Plus restorations placed with the bulk/transtooth-illumination technique, the hardness values at 3.0 and 3.5 mm were significantly lower than those at 0.5 mm (*P* < .05), and the hardness values from 0.5 to 2.5 mm were not significantly different (*P* > .05).

**DISCUSSION**

Polymerization shrinkage has been of major concern to dental clinicians placing direct composite restorations in posterior teeth. On the one hand, a good adhesive seal helps prevent microleakage and ensure that the composite will reinforce the tooth structure, but, at the same time, such a bond will constrain polymerization shrinkage and thus induce stresses in the tooth structure. Use of...
Bulk placement has been suggested to produce lower shrinkage stresses, but sufficient depth of cure may require an incremental technique.

**Bulk versus incremental placement.**

**Shrinkage stresses.** First, we tested the effect of bulk versus an incremental technique on shrinkage stresses by recording cuspal deflection. Often, clinicians fill deep restorations in more than two increments. Additional increments may increase the cuspal deflection owing to accumulation of incremental deformations of the weakened cavity walls, but they still can be necessary to ensure good cure and bonding. We chose a two-layer incremental method because 2 mm usually is regarded as the maximum thickness for curing a composite and because the placement procedure was more controllable and thus more consistent. We found no significant difference in cuspal deflection between the bulk and incremental methods. Although deflection is not a stress itself, it is a manifestation of internal stress conditions within a tooth. For similar tooth and restoration shapes and properties, cuspal deflection provides a reasonable reflection of internal stresses. We obtained comparable shapes by matching teeth and standardizing cavity sizes, and we assumed tooth properties to be similar. To ensure similar composite properties in both bulk and incrementally filled restorations, we used X-tra fil composite, which the manufacturer claims can cure to a depth of as much as 4 mm. The microhardness values confirmed that curing levels with both methods were similar at all depths, and they showed no statistically significant differences (Table 2 and Figure 3A). The X-tra fil thus delivered the deep curing claimed by the manufacturer regardless of filling technique. Given that the conditions and cure were similar between the bulk and incrementally filled restorations and that the cuspal deflections were not significantly different, we conclude that differences in shrinkage stresses between the bulk and two-layer incremental placement methods could not have been substantial.

**Curing depth.** If the difference in shrinkage stress between bulk and incremental techniques thus was not a major issue, the next question is whether adequate cure could be ensured with a bulk technique. To test this, we used Filtek Supreme Plus, which the manufacturer recommends using in increments of no more than 2 mm thick. We compared conventional bulk and incremental techniques with a bulk/transtooth-illumination technique, which has been reported to cure the deep part of a restoration effectively. The cuspal deflection results did not show significant differences among the three curing techniques. However, microhardness, which within a resin-based material has a good correlation with degree of cure for a broad range of conversion levels, was affected by the different filling techniques. For the conventional bulk technique, we noted a continuous drop in the hardness values as the depth increased (Figure 3B). At 2.0 mm and below, hardness values of Filtek Supreme Plus applied in the bulk technique were significantly lower than those of the same material placed with the incremental and bulk/transtooth-illumination techniques. This confirms the general concern that a conventional bulk technique compromises depth of cure and the consequent recommendation for incremental methods. Since light attenuation in composite is the same regardless of whether the material was placed in bulk or with an incremental technique, the hardness values of material placed with the incremental technique followed the same con-

### Table 2: Mean (standard deviation) Vickers hardness numbers at various depths.

<table>
<thead>
<tr>
<th>MATERIAL AND TECHNIQUE</th>
<th>VICKERS HARDNESS NUMBER AND DEPTHS IN MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>X-tra fil*</td>
<td></td>
</tr>
<tr>
<td>Bulk</td>
<td>121.8 (10.1)*</td>
</tr>
<tr>
<td>Incremental</td>
<td>121.9 (18.2)*</td>
</tr>
<tr>
<td>Filtek Supreme Plus†</td>
<td></td>
</tr>
<tr>
<td>Bulk</td>
<td>101.3 (1.7)*</td>
</tr>
<tr>
<td>Incremental</td>
<td>102.3 (1.8)*</td>
</tr>
<tr>
<td>Bulk/transtooth</td>
<td>107.4 (5.2)*</td>
</tr>
</tbody>
</table>

* X-tra fil is manufactured by VOCO, Cuxhaven, Germany.
† Same letters denote mean values that were not significantly different among depths within the same resin-based composite material and technique (according to analysis of variance/Student-Newman-Keuls post hoc test, P > .05).
‡ Filtek Supreme Plus is manufactured by 3M ESPE, St. Paul, Minn.
Continuous drop as found in material placed with the bulk technique, except that there was a step increase at a depth of 2.0 mm (Figure 3B). The step increase in hardness at 2.0 mm corresponded well with the boundary between the first and second increments and thus represented the superficial composite of the first increment, which received more light energy (and higher cure) than the deeper composite of either increment. Incremental techniques thus improved the overall cure within a restoration.

**Transtooth illumination.** Little published information exists about the effectiveness of transtooth-illumination techniques. Although there is some skepticism about the effectiveness of techniques that involve curing through tooth structure, investigators in two studies reported that light could penetrate enamel and dentin walls and cure the inner portion of a restoration with no difference compared with the incremental technique, provided that the composite was cured from the buccal, lingual and occlusal directions.\(^13,14\) In this study, we found that Filtek Supreme Plus restorations had significantly higher hardness when we used a bulk/transtooth-illumination technique than when we used the conventional bulk technique and also had significantly higher hardness values up to a depth of 1.5 mm than did restorations placed with an incremental technique (Figure 3B). In addition, the hardness values did not drop significantly until a depth of 3.0 mm (Table 2), which suggests a good overall polymerization. The superior performance of the transtooth-illumination technique in our study could be a result of the ability of light to penetrate enamel walls,\(^13\) or it simply could arise from the fact that the amount of light energy applied with this technique was higher. In the bulk/transtooth-illumination technique, we cured the material for 20 seconds simultaneously with two curing lights through the buccal and lingual surfaces, followed by curing for 20 seconds from the occlusal direction (total, 60 seconds), whereas for the bulk and incremental techniques we cured for 20 seconds from the occlusobuccal and for 20 seconds from the occlusolingual direction (total, 40 seconds). Note that the light sources we used in the study were current-generation curing lights with high outputs that could cure adequately through the tooth structures. The bulk/transtooth-illumination technique resulted in coronal deformation values that were slightly higher than those found with the incremental and bulk techniques, but these were not statistically significantly different (Table 1). Therefore, there was no indication that the extra energy applied in the bulk/transtooth-illumination technique had increased shrinkage stresses significantly.

**Hardness values.** There is no clear consensus about how much conversion should be considered adequate. A bottom-to-top hardness ratio of 0.8 represents a bottom-to-top degree of cure of 0.9 and may be considered adequate curing.\(^21\) In this study, we found that when cured with a conventional bulk technique, a Filtek Supreme Plus restoration at depths of 3.0 and 3.5 mm had hardness values lower than about 80 percent of the value at 0.5 mm depth, whereas with an incremental or bulk/transtooth-illumination technique, values at all measured depths were higher than 80 percent. X-tra fil had relative hardness values higher than 90 percent at all depths, regardless of

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**Figure 3.** Vickers hardness numbers at various depths in the restorations: **A.** X-tra fil (VOCO, Cuxhaven, Germany) and **B.** Filtek Supreme Plus (3M ESPE, St. Paul, Minn.). Same letters denote mean values that were not significantly different between filling techniques at the same depth (\(t\) test for X-tra fil and analysis of variance and Student-Newman-Keuls post hoc test for Filtek Supreme Plus, \(P > .05\)). mm: Millimeters. TT: Transtooth (illumination technique).
the filling technique used. Note that we could not calculate a bottom-to-top ratio because our hardness measurements started at 0.5 mm below the top surface. Readers also should be aware that we sectioned, embedded and polished the composite restorations to achieve a surface suitable for microhardness measurements. Any of these procedures could have increased the hardness values. Cheng and Douglas found that hardness values increased more than 25 percent after restorations underwent polishing. Thus, hardness values of clinical restorations with the composites chosen for this study may be lower than the values reported here. On the other hand, clinical values could turn out to be higher for a less opaque shade of Filtek Supreme Plus that most clinicians prefer because it cures better than the relatively opaque A2D shade used in this study. We selected the A2D shade to allow the LavaScan ST optical scanner to digitize the restoration.

In summary, the effect of different filling techniques on cuspal flexure was not significant in this study. Although shrinkage stress levels cannot be simply extrapolated from cuspal flexure, the results of our study suggest that clinicians should be more concerned about a thorough cure of a restoration than about placement technique. Long-term performance of a restoration is likely to depend more on the quality and physical properties of a restoration than on the minor differences in initial shrinkage stresses caused by placement techniques.

CONCLUSIONS

Within the limitations of this in vitro study, we conclude that the filling techniques we used resulted in no significant difference in the amount of cuspal deflection between the composites we evaluated.

We found that X-tra fil had adequate curing up to at least 3.5 mm when placed in one bulk increment, with no significant difference in hardness from that of X-tra fil placed with the incremental technique. Filtek Supreme Plus had lower hardness values, and thus a lesser extent of cure, when restored with bulk technique than when restored with the incremental or bulk/transtooth-illumination techniques. In addition, the bulk/transtooth-illumination technique produced higher hardness values in the superficial layer of the Filtek Supreme Plus in comparison with the incremental technique.

The transtooth-illumination technique, which requires light curing from buccal, lingual and occlusal directions, can improve the depth of cure of composites placed in bulk without increasing cuspal deflection.

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